

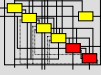


Felix Schmid, School of Civil Engineering and
Birmingham Centre for Railway Research and Education

U Who Needs Adhesion? B

A not entirely Heritage Focused Talk
about Vertically Challenged Railways

IMechE Heritage Lecture 2011-10-31, Birdcage Walk



Who needs adhesion?

Felix Schmid, as seen by himself

- Long term academic but surprisingly pragmatic in approach;
- A one year sabbatical as a Swiss railway inspector led to post with University of Sheffield's ARRC;
- Very, very, VERY little interest in trains, tracks and railways;
- Railways provide a decent salary, paid directly into the bank account, no need to go to the office to collect the cash;
- Railways keep him out of trouble and out of the shops;
- 10+ years of responsibility for MSc in Railway Systems Engineering at The University of Sheffield with 200 graduates;
- 6 years of Responsibility for MSc in Railway Systems Engineering and Integration at The University of Birmingham;
- Wears loud cycling jackets in winter and whenever it rains.

Slide No: 2

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Who needs adhesion?

Spot the Presenter amongst his Team



Who needs adhesion?

Overview of Presentation

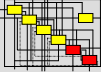
- Why do railways become vertically challenged?
- Problem of steel wheels on steel rails;
- Adhesion is an over-rated quality:
 - It varies and does not always work;
 - Critical in braking – but we have solutions.
- Alternatives:
 - ‘Enhanced’ adhesion by means of rubber tyres;
 - Enhanced adhesion by means of Fell rails;
 - Hidden use of adhesion on cable hauled cars;
 - Elimination of need for adhesion by Mr. Brunel;
 - Elimination of need for adhesion on funiculars;
 - Reduction of need for adhesion on rack railways;
 - Elimination of adhesion by modern drive technology.

Slide No: 4

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Who needs adhesion?



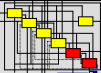
Why might Railways go Up Hills?

- Because production is in the valleys and consumption is on the hills?
- Because workers live on the hills and eat their crust in the valleys?
- Because raw materials are found in the valleys and production is in the mountains?
- To overcome geographical obstacles when carrying goods from A-B?
- To show that it is possible to overcome gravity?
- For fun? To please the punters? For money?

In this talk, we shall focus on (i) fun and (ii) (money)

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Who needs adhesion?



The Mountains in the Romantic Period



Heinrich Keller, 1815, Gondo from the Southeast

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Who needs adhesion?

The Rigi and the Romantic Period



Panorama from the Rigi

Heinrich Keller, 1815

Slide No: 7

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Who needs adhesion?

Awaiting the Sun's Rise on the Rigi



Mark Twain tried to see the Sunrise but never made it:
Getting up early was TOO hard.

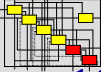
Keller, 1816

"Frau Bürgi, Mr. Bürgi, zwei Sachsen"

Slide No: 8

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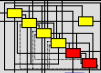


Who needs adhesion?

1850s Solution: let's build a Railway!

- Historically, railways had been built for trade and travel; i.e., entirely utilitarian motives;
- Funding for railways had always come from business and governments:
 - To access lower cost raw materials;
 - To reduce cost of shipping goods;
 - To access lower cost labour;
 - To transport armies;
 - To invest money for profit.
- Tourist travel to cities and seaside resorts were secondary factors in building railways;
- The journey as an experience in itself did not exist.

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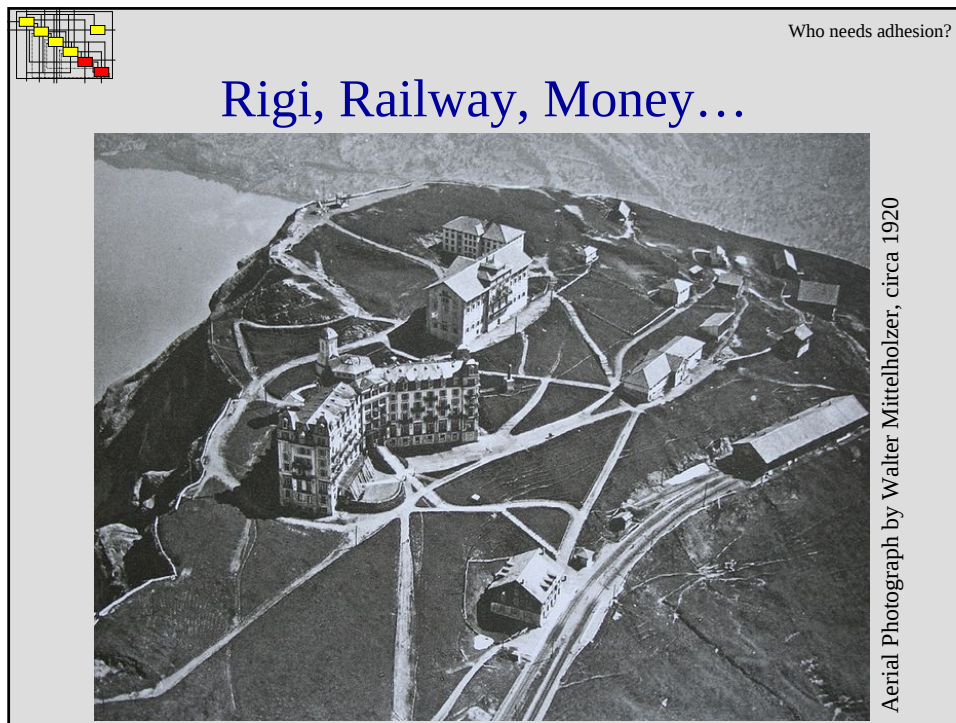


Who needs adhesion?

But 'Bellevue' tended to be high up...

- Romantic period had great faith in its engineers:
 - Mr Brunel and Mr Turner got on well and respected each other.
- But, initially, great engineers had limited trust in adhesion:
 - A nice railway was a flat railway: Manchester to Liverpool and GWR.
- Eventually, railway engineers had to conquer hills where:
 - Topography militated against railways with shallow gradients:
 - Markets were in the wrong places;
 - No space to build a well graded alignment;
 - Low gradients resulted in excessively long alignments.
 - Financial issues:
 - Journey time demanded a short route for competitiveness.
 - Cost of a well graded alignment was unaffordable.
- Conquering gradients became a game;
- Conquering a gradient might bring revenue:
- Engineers are not known for ignoring financial incentives!

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Felix Schmid, School of Civil Engineering and
Birmingham Centre for Railway Research and Education

Most Early Railways Used Adhesion to Propel and Brake Trains

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Who needs adhesion?

But not Mr Blenkinsop and Friends



Slide No: 13

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Who needs adhesion?

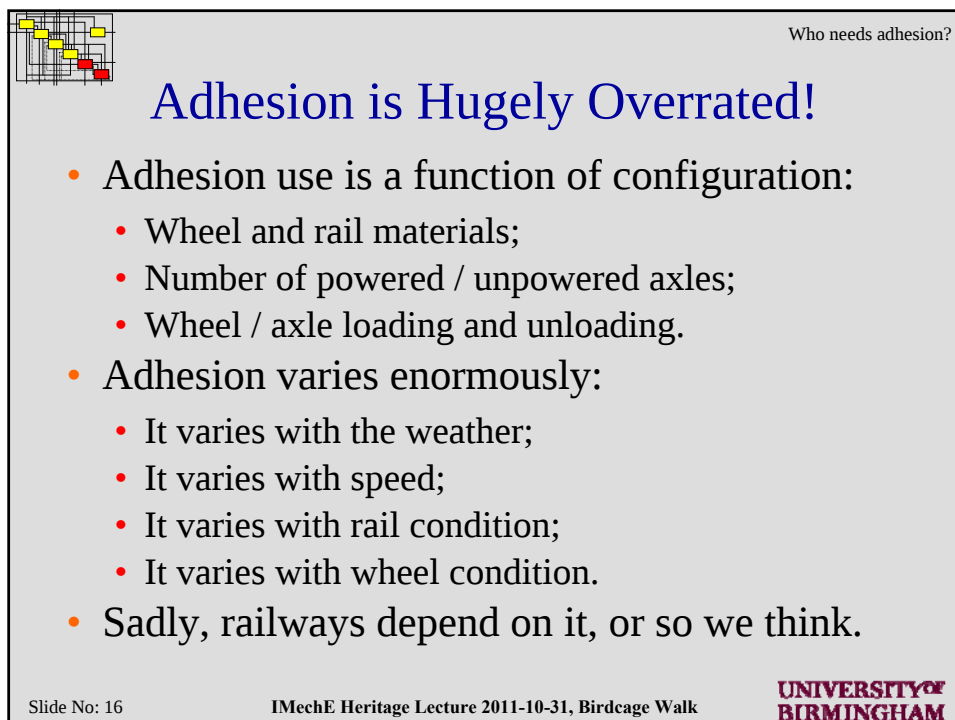
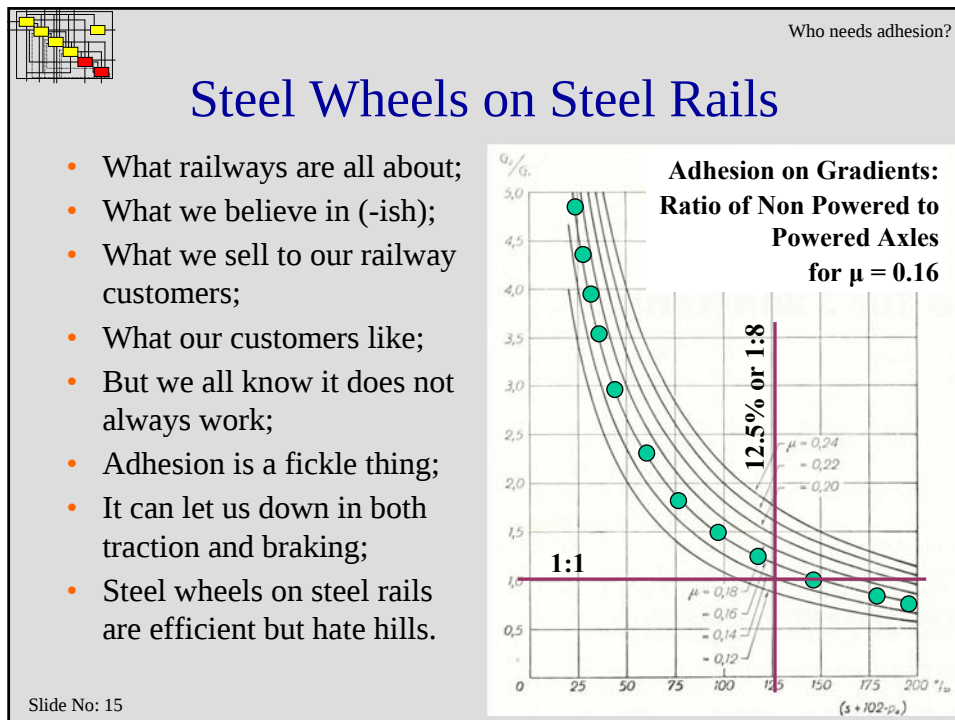
Adhesion became Brunel's Nightmare

- Why do railways need adhesion?
 - To accelerate (0.5 to 1.2 m/s^2);
 - To brake with wheels (0.5 to 1.5 m/s^2);
 - To abrade the wheels and rails, thankfully;
 - To brake with track brakes (2.4 m/s^2);
 - To overcome gravity when going uphill.
- Why do railways not want friction?
 - Increases energy use;
 - Generates noise;
 - Abrades the wheels and rails and reduces their life.

Slide No: 14

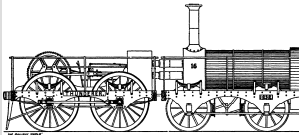
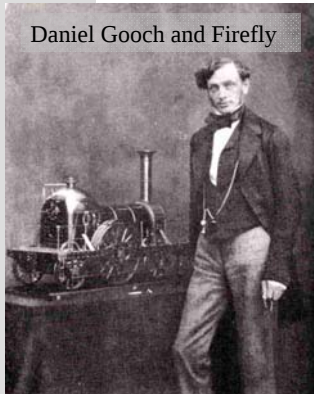
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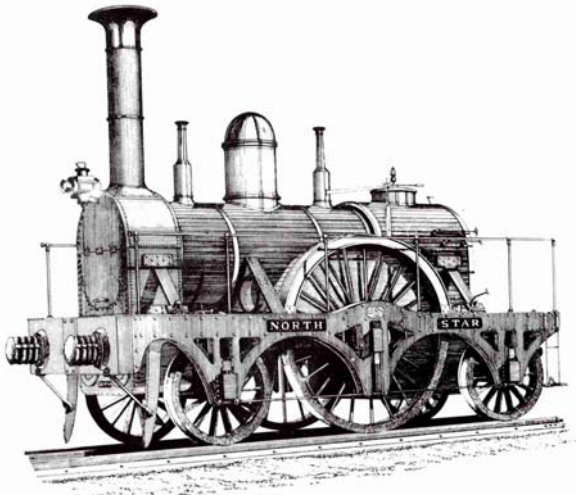


Who needs adhesion?

IK Brunel had Problems with Friction

Daniel Gooch and Firefly



North Star, delivered to the Great Western in 1837

Who needs adhesion?

IK Brunel came to Distrust Adhesion

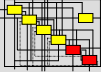


William Heath Robinson, Railway Ribaldry

- Construction of Great Western Railway had reached Exeter;
- South Devon Railway Company received royal assent for stretch from Exeter to Plymouth through Dawlish, in July 1844;
- Isambard Kingdom Brunel plans the route to Plymouth
- Railway traffic expected to be highly seasonal, limiting revenue;
- IKB worried about 'steep' grades that were necessary to limit cost;
- Up to 2.5% (1 in 40) between Newton Abbott and Plymouth;
- Brunel suggested use of adhesion-independent technology.

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Who needs adhesion?



Atmospheric Propulsion Principle

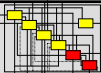
- Atmospheric railway invented by Clegg, assisted by brothers Jacob and Joseph Samuda of London:
 - A pipe with a slot in top is placed between the rails;
 - 'Locomotive' is hooked to a piston in the pipe;
 - Pumping stations create vacuum in the pipe ahead of train and atmospheric pressure pushes locomotive along piston;
 - First line built in Ireland from Kingstown to Dalkeith.
- On SDR, 8 pumping stations allowed operation at up to 68 mph (100 km/h), with a train weighing just 28 t;
- Leather seals perish quickly (eaten by rats) and Brunel had to abandon the system after one year;
- 1:40 gradients are no longer a problem in 1848.

Slide No: 19

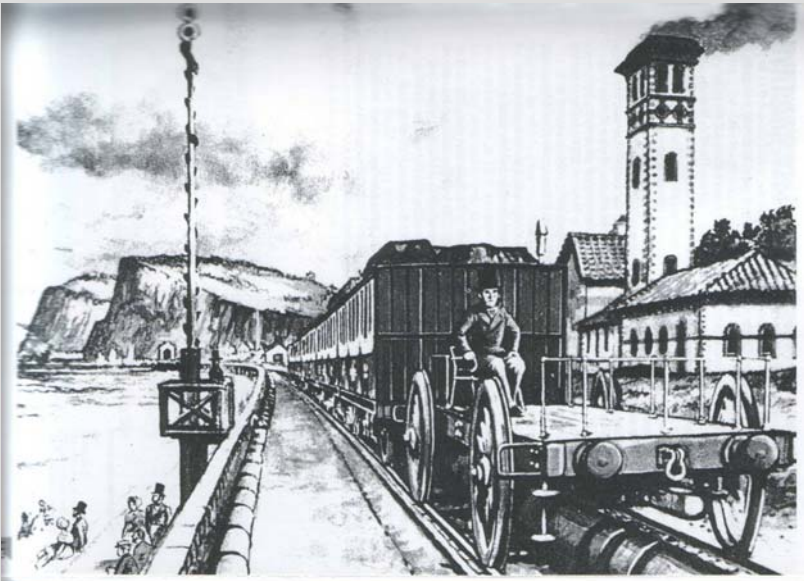
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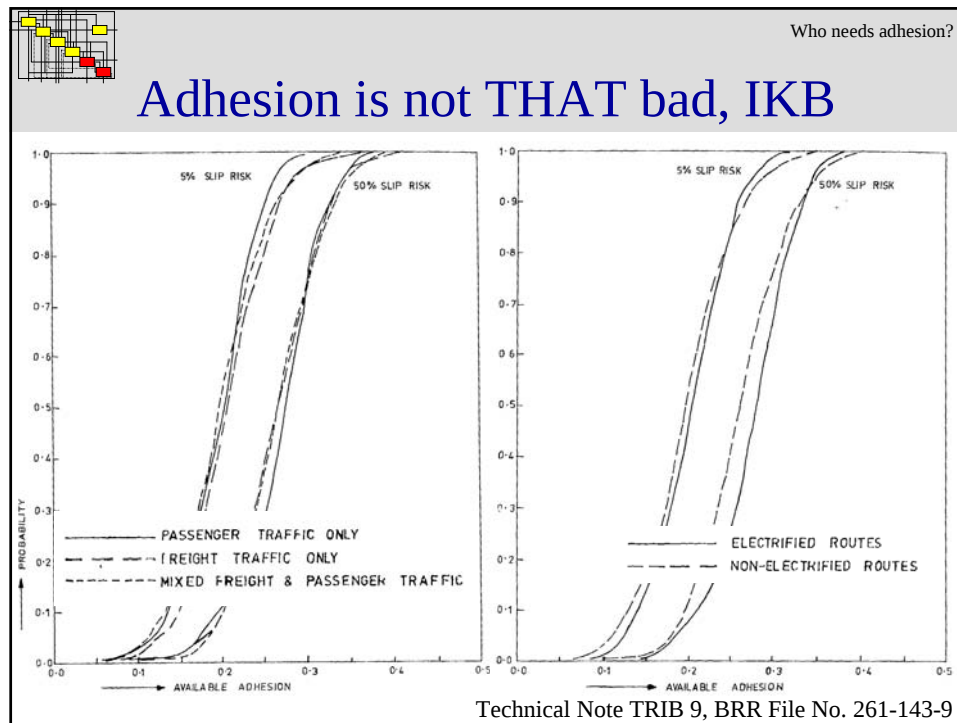
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Who needs adhesion?



Sadly, No Cigar, Mr Brunel!





Who needs adhesion?

Adhesion Limits: Üetliberg (7%)



Slide No: 23

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Who needs adhesion?

Adhesion Limits: Bernina Bahn (7%)

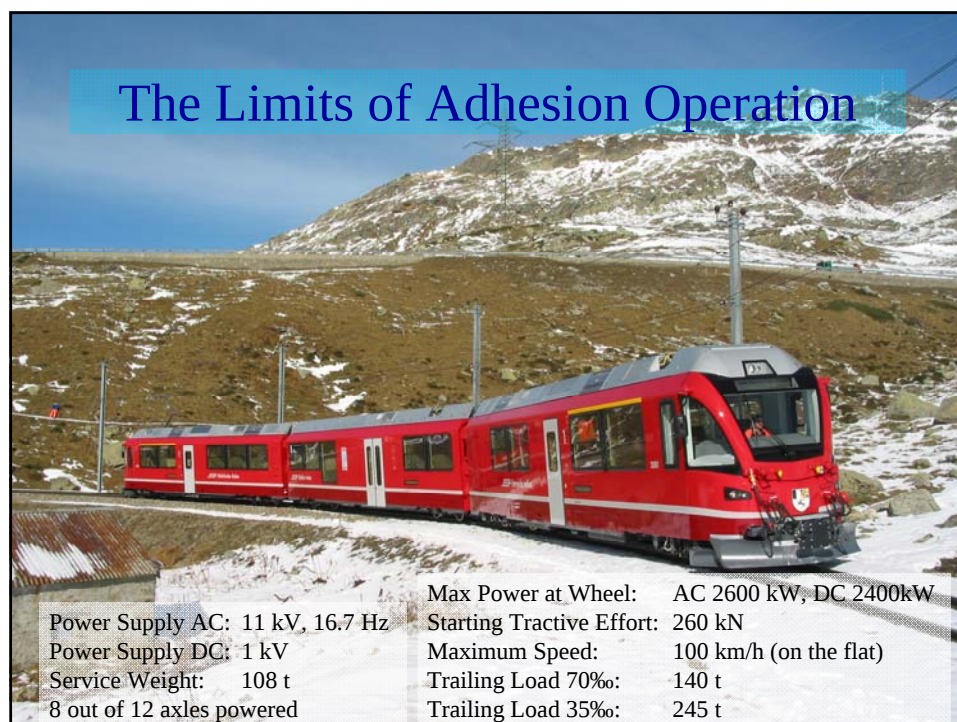


© Kurt Jaehnig

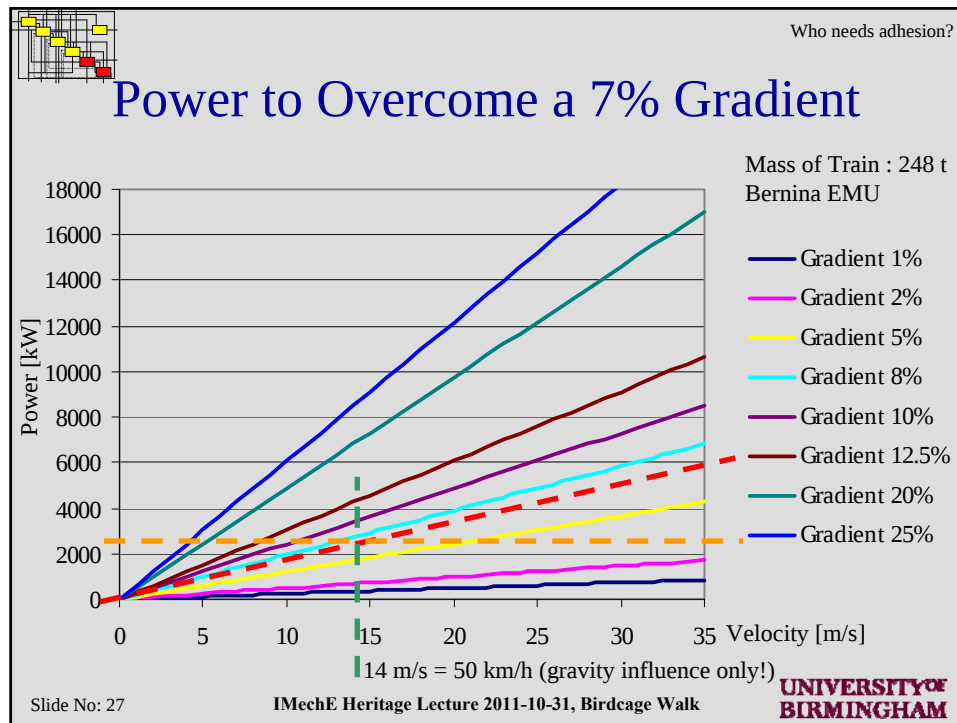
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Power Supply AC: 11 kV, 16.7 Hz	Max Power at Wheel: AC 2600 kW, DC 2400kW
Power Supply DC: 1 kV	Starting Tractive Effort: 260 kN
Service Weight: 108 t	Maximum Speed: 100 km/h (on the flat)
8 out of 12 axles powered	Trailing Load 70%: 140 t
	Trailing Load 35%: 245 t



Who needs adhesion?

Saint-Gervais to Vallorcine Railway

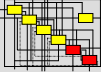
- Alignment rises from Saint Gervais Le Fayet station (altitude: 581 m) to Col des Montets tunnel (altitude: 1365 m), then drops to station at Swiss border (altitude: 1100 m);
- Maximum gradient 9 % (1 in 11), between Servoz and Les Houches, over a distance of 2000 m;
- Until about 1980 stretches steeper than 4 % (1 in 25) were fitted with a central braking rail:
 - Based on a spring applied grip with pads;
 - Supplemented rheostatic brake and used as parking brake.
- Electrified with 3rd rail at 850 VDC (580 V at start).

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Who needs adhesion?



Saint-Gervais to Vallorcine (9%)

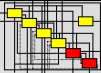


LUL does not have a monopoly
on strange four-rail systems

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Who needs adhesion?



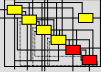
Adhesion Limit: Snaefell (9%)



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Who needs adhesion?



Adhesion Limits: Supertram (10%)

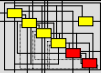


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Who needs adhesion?

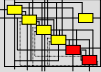


Sheffield Supertram at University Stop



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Who needs adhesion?



Lausanne Metro Line M2: 12%

- Opened as a funicular from Lake Geneva to Lausanne station in 1877;
- Converted to Strub rack system in 1959;
- Converted to derivative of Paris rubber-tyred system;
- Opened 19 September 2008 as steepest such system;
- Fully automatic operation;
- Maximum gradient: 12% (nearly 1:8);
- Average gradient 6% over length of 6 km.

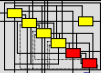


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Who needs adhesion?



Adhesion Limits: Tram Lisbon (12%)



Slide No: 34

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Who needs adhesion?

Adhesion Limits: Tram Lisbon (12%)



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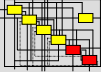
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U B

What can we do to go up even steeper hills?

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Who needs adhesion?

Let's Enhance Adhesion by Force

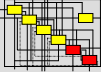
- John Barraclough Fell trials a new drive system in Derbyshire in 1863/4, on Whaley Bridge incline:
 - Reaction rail installed in centre of track;
 - Horizontal drive & braking or braking only wheels;
 - Pressed against centre rail using springs or air pressure.
- Test for installation in 1866 on temporary 48 mile long 1100 mm gauge Mont Cenis Pass railway (Red Route).



Slide No: 37 IV



Who needs adhesion?



Fell Rail Installations Worldwide

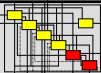
- Construction and mail railway (the All Red Route) the across *Col du Mont-Cenis* in France, in operation from 1868 to 1871;
- *Cantagallo Railway* in Brasil re-used the Mont-Cenis equipment until 1960;
- *Rimutaka Incline* in New Zealand from 1878 to 1955;
- *Roa Incline* in New Zealand from 1909 to 1966;
- *Rewanui Incline* in New Zealand from 1914 to 1965
- Puy-de-Dôme mountain railway from 1907 to 1926;
- Snowdon Mountain Railway, Isle of Man, braking hard to this day!

Slide No: 39

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Who needs adhesion?



Or Cheat: Use Friction to Grip a Rope



The Cable Cars at Smedley St., Matlock.

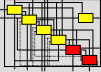
Matlock, Derbyshire, Smedley St. and Bank 1:5½, 1893-1927

Slide No: 40

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Who needs adhesion?



Most Successful in San Francisco

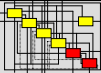


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Who needs adhesion?



Inventor had to Brave First Test

- Some 10 routes built;
- Features of system:
 - Central power house;
 - Basic vehicles;
 - Coasting around curves;
 - Coasting at crossings.
- 5 started at the Market St. Ferry Terminus:
 - A cable car every 15s!!!
- 3 routes survive, with some shared running.



Slide No: 42

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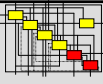
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U Or connect the train to a rope, full stop B

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Who needs adhesion?

Maybe just a Cliff Lift in the Sun



Who needs adhesion?

Or a Cliff Lift in Rainy Bridgnorth



Slide No: 45

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Who needs adhesion?

Or, Better, a Proper Funicular

Polybahn Limit: 25%, 176 m long



UBS Polybahn Zürich, © M Porcius Cato, 2005

Slide No: 46

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Who needs adhesion?

Muottas Muragl Limit: 54%



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Who needs adhesion?

Niesen Bahn Limit: 66%



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Who needs adhesion?

Schwyz-Stoos Limit: 78.1%



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Who needs adhesion?

Piotta-Ritom Limit: 87.8%

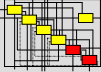
World's steepest funicular in public service



Slide No: 50

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Who needs adhesion?

Some Funiculars go VERY Fast



10 m/s

200 passengers

30 t total mass

16 t passenger mass

48% gradient

753 kW power
(gradient only),
assuming balancing
of car masses

Parsenn Railway I

Slide No: 51

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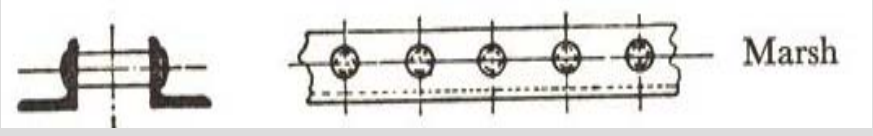
And along came Mr Marsh
and invented cog railways



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Who needs adhesion?

First: Mr Marsh's Rack and Track



Marsh



WJ Kimberle



Slide No: 53

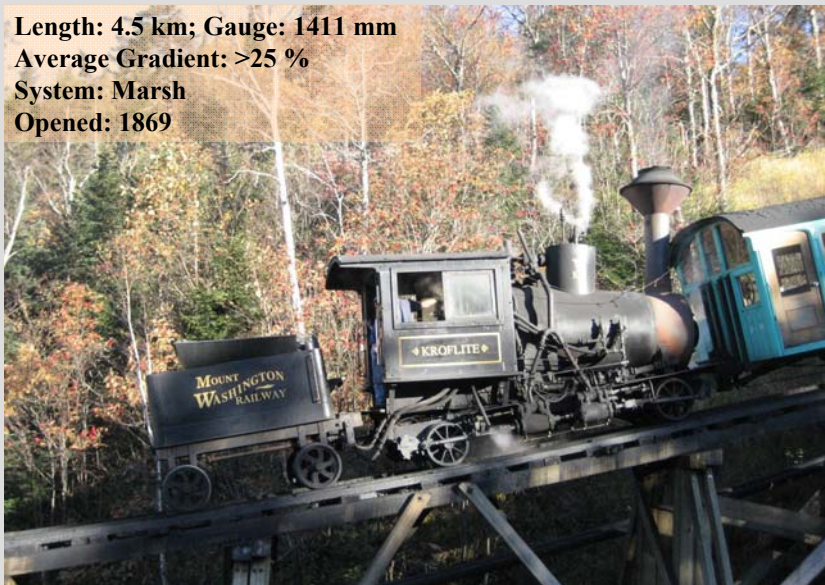
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Who needs adhesion?

Mount Washington Limit: 37.41%

Length: 4.5 km; Gauge: 1411 mm
Average Gradient: >25 %
System: Marsh
Opened: 1869

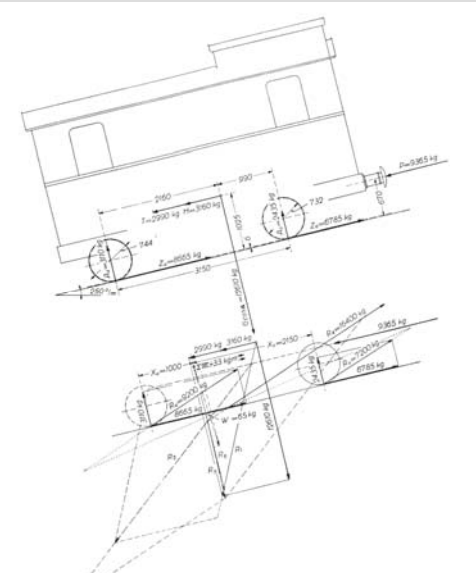


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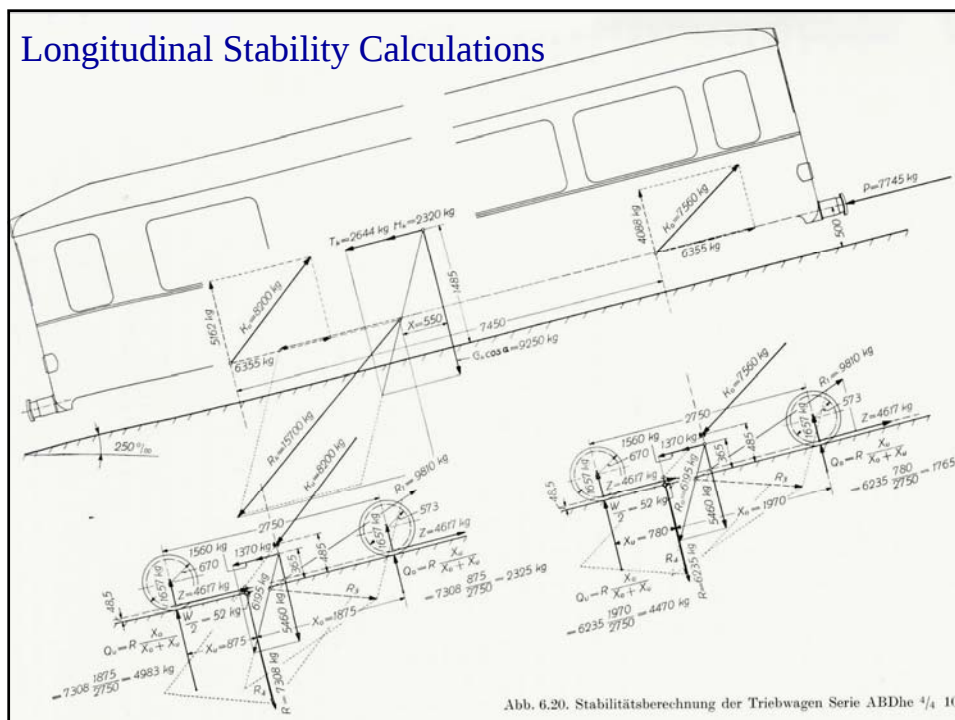
Who needs adhesion?

The Swiss would not have allowed it!

- Rack and pinion systems are often narrow gauge;
- Terrain tends to be dodgy;
- Lateral stability can be managed with good track;
- Climbing out of the rack is quite another issue;
- Longitudinal stability calculations limit gradient to some 30%, in Swiss eyes;
- But Riggensbach had learnt from Marsh.



Slide No: 55 1



Who needs adhesion?

Mount Washington is Up-to-Datish...



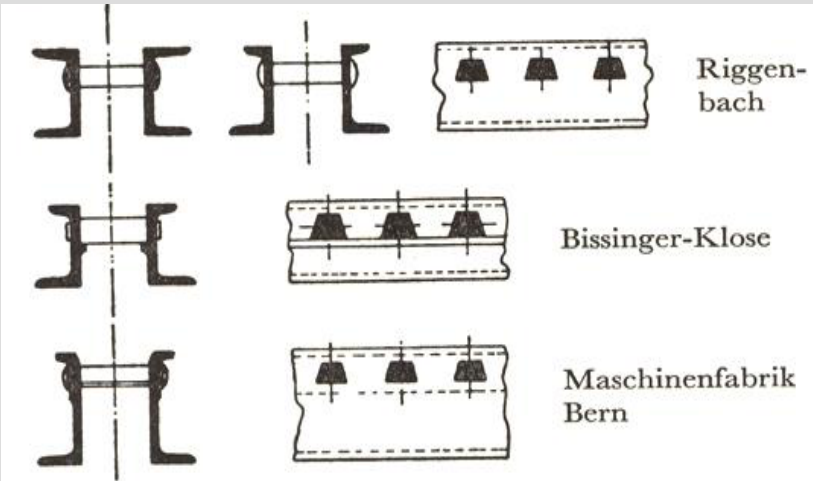
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Who needs adhesion?

And Other Rack Types Followed...



Rignbach

Bissinger-Klose

Maschinenfabrik Bern

Slide No: 58

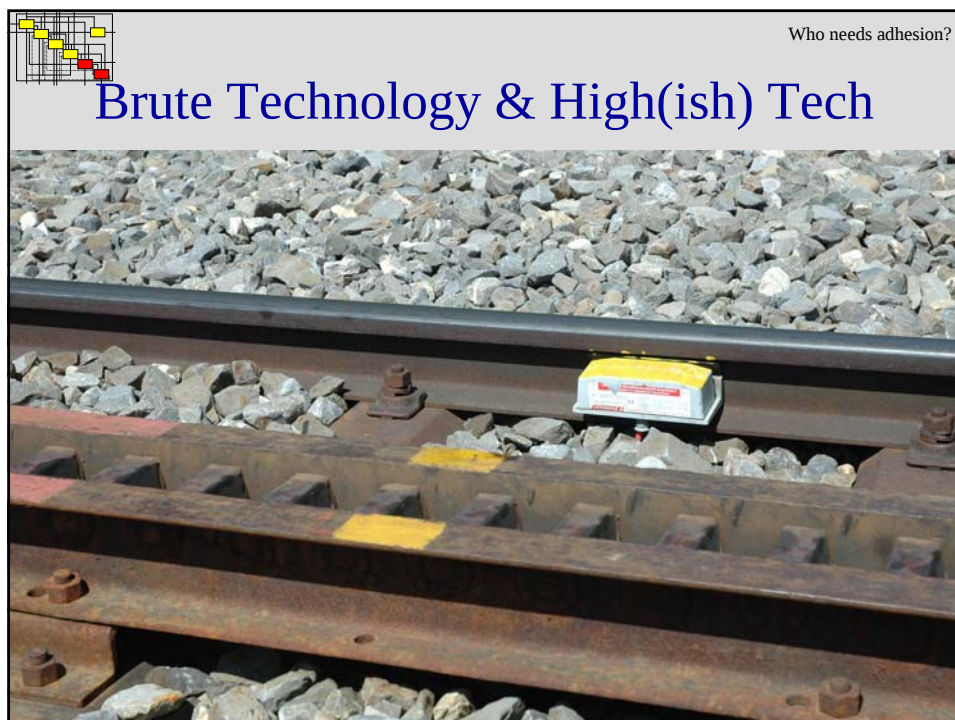
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Riggenbach's Earliest Development

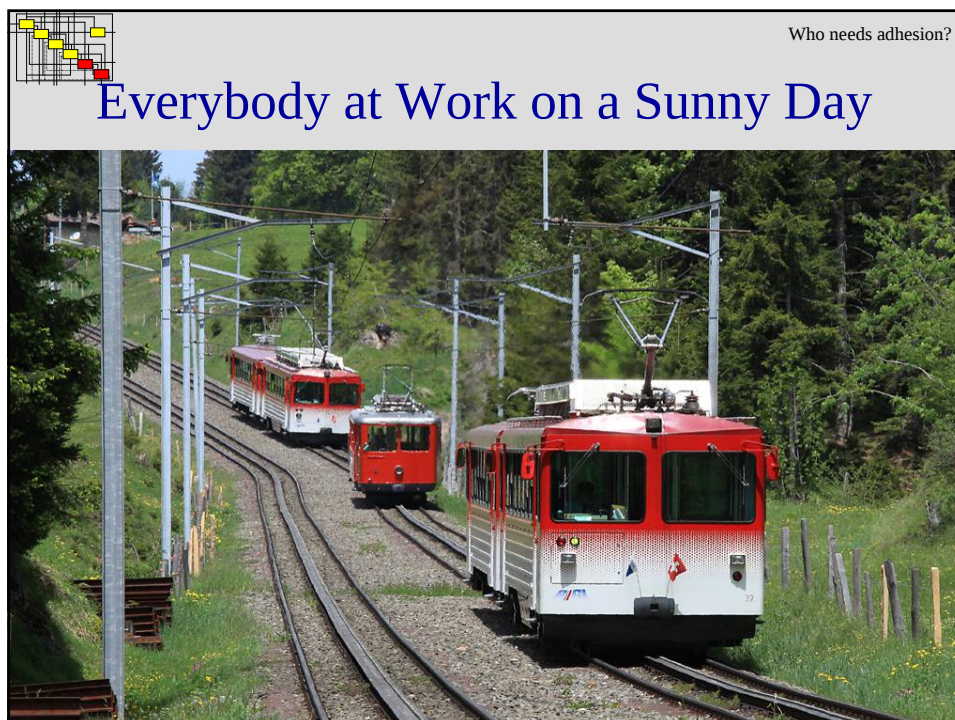
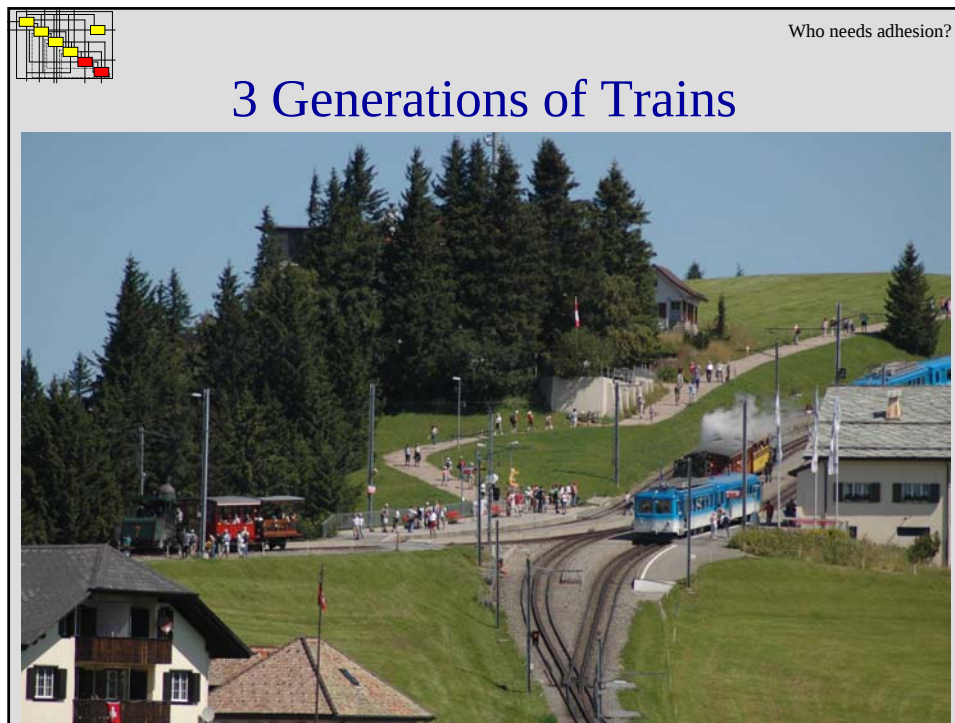
Who needs adhesion?



Brute Technology & High(ish) Tech

Who needs adhesion?





Who needs adhesion?

And then Rigenbach went to Brazil



Corcovado Railway
Length: 6.7 km
Gauge: 1000 mm
Gradient: 30%
3Ø AC Supply
System: Rigenbach

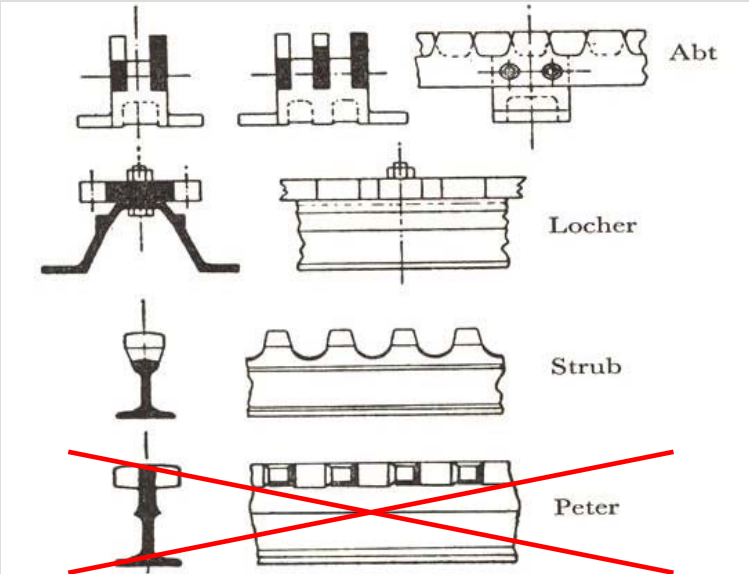
Slide No: 65

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Who needs adhesion?

And Yet More Designs Followed...



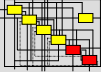
Abt

Locher

Strub

Peter

Who needs adhesion?



Mr Abt had a More Flexible Idea



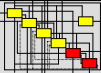
A. Michel, Oberalp Railway, 2 Lamellen

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Who needs adhesion?



Brienzen-Rothorn Bahn Switzerland



Length: 7.5 km; Gauge: 800 mm
Gradient: 25 %
System: Abt 2 Lamellae

Who needs adhesion?

Signalling not a Requirement?



© By F. Geisser, bahnbild.ch

Who needs adhesion?

Matterhorn-Gotthard Bahn (MGB)

Combined Adhesion (101.5 km) / Rack and Pinion (39.3 km)



Gauge: 1000 mm
Gradient: 4% / 12.5%
System: Abt 2 Lamellae

Slide No: 70



Who needs adhesion?



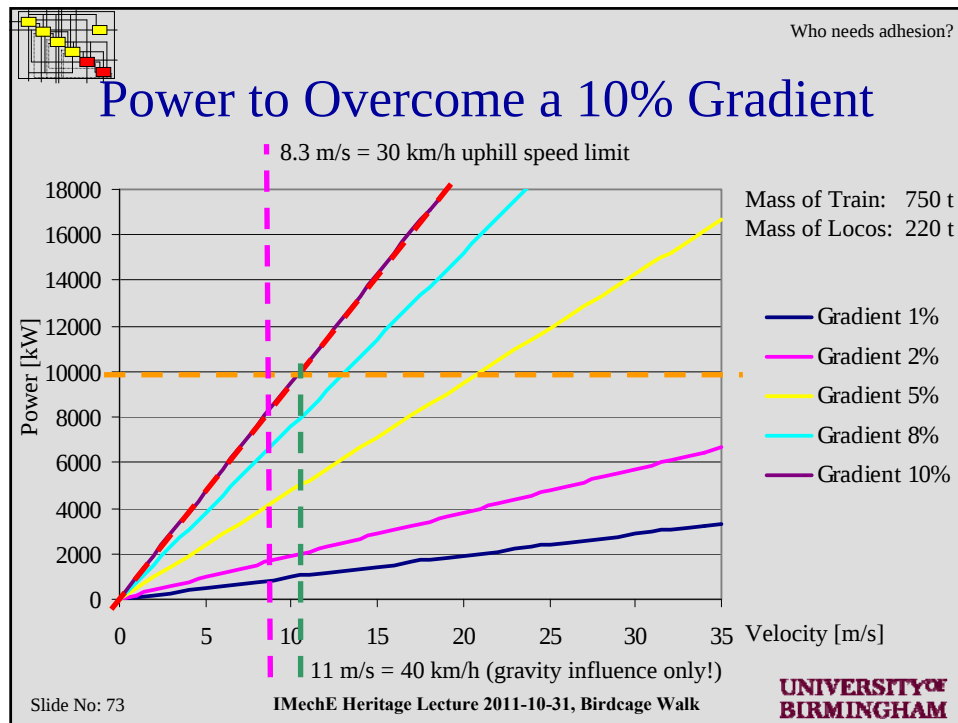
2012: New Locos for MRS Logistica

São Paulo to Santos: 9 km
Gauge: 1600 mm
Gradient: 10.4 %
System: Abt 3 Lamellae
Type: BoBo, 4 pinions, 5 MW
Power: 3000 V DC
Weight of loco: 110 t
Combined rack and adhesion

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Who needs adhesion?

The Strub Rack is the Best...



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Who needs adhesion?

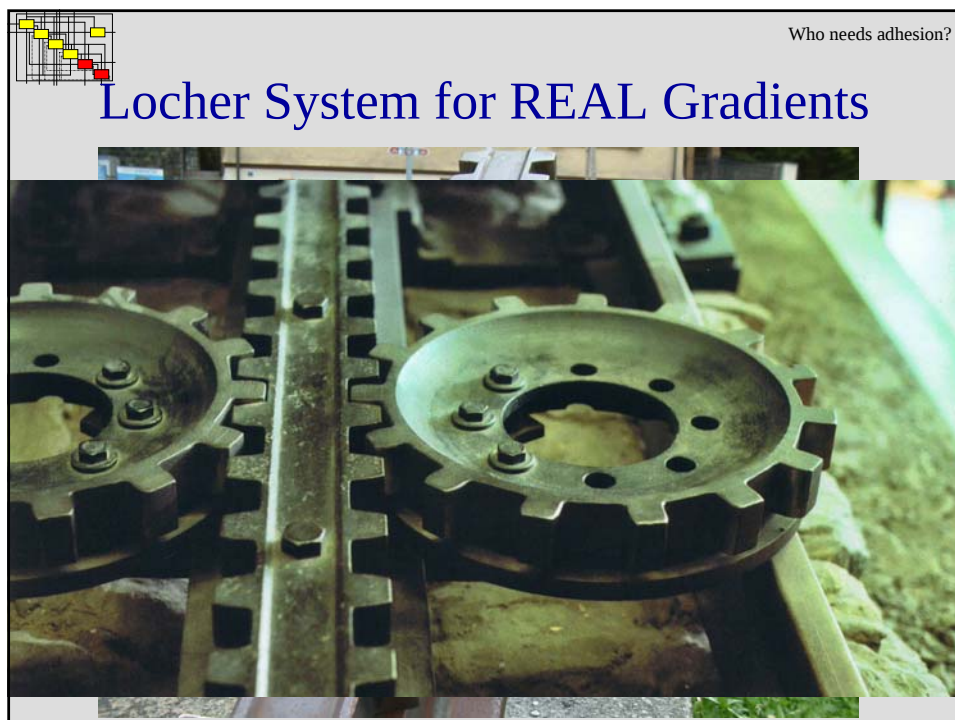
The Jungfraubahn with Strub Rack



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Who needs adhesion?

Quite Basic Kit, to be Honest



NOTE: Light Weighting Efforts

Slide No: 79

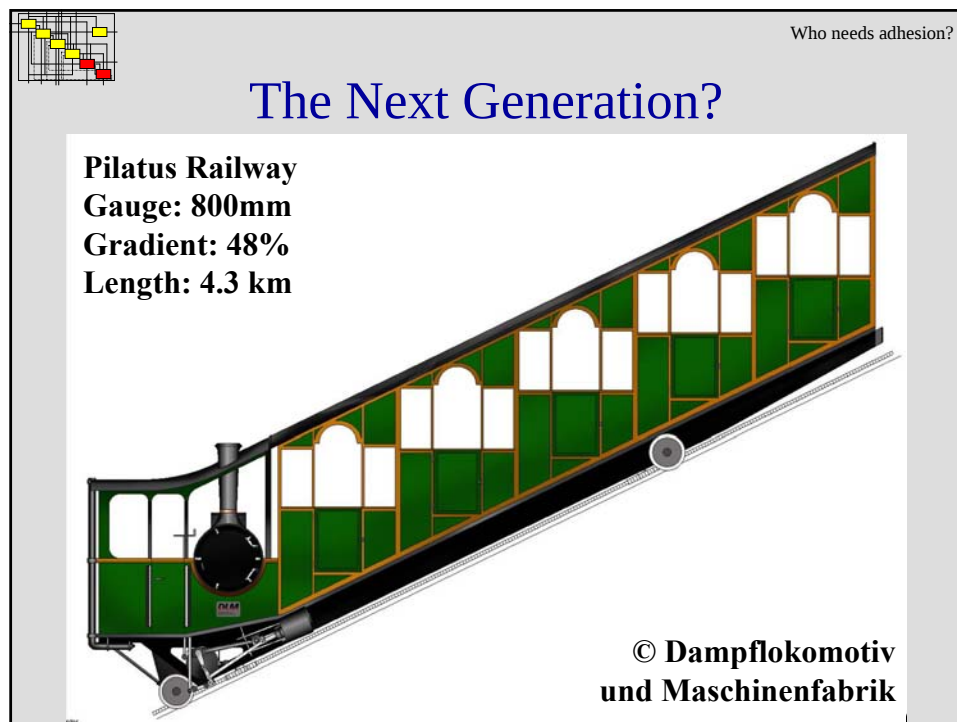
Who needs adhesion?

Approved by HM Railway Inspector

Gauge: 800 mm
Gradient: 48%
System: Locher



PILATUS
27



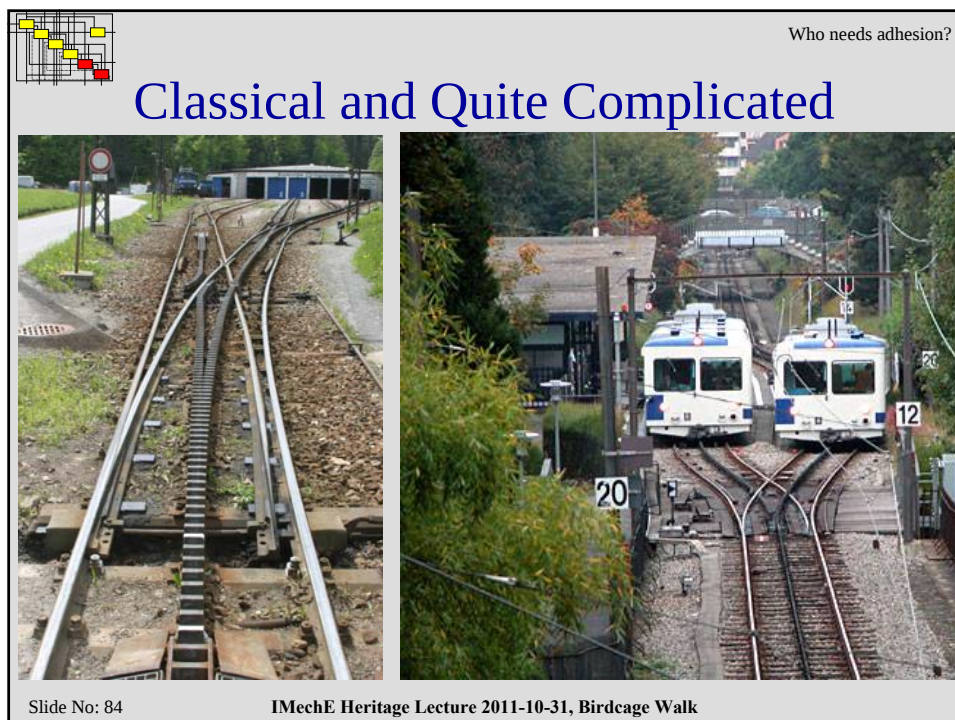
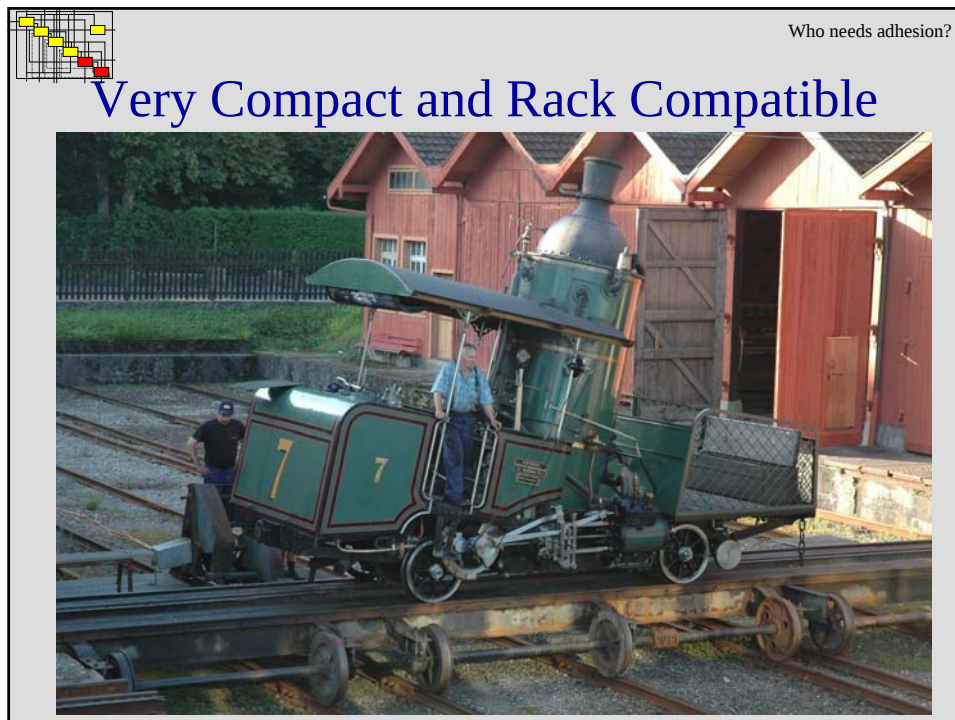
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Institution of MECHANICAL ENGINEERS

Felix Schmid, School of Civil Engineering and
Birmingham Centre for Railway Research and Education

Points / Turnouts / Switches and Racks

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Who needs adhesion?

Bendy Points on the Rigi



Slide No: 89

Who needs adhesion?

Linear Motor Drive Technology



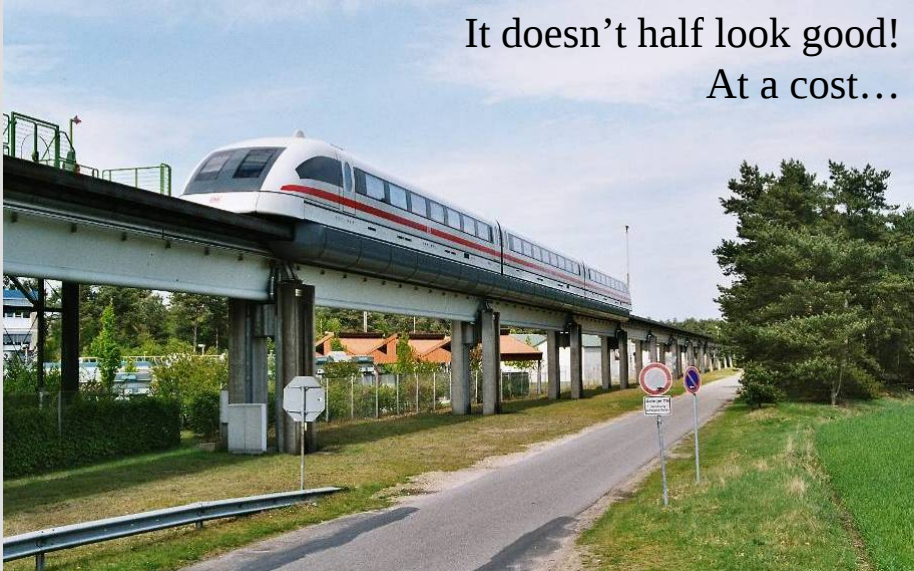
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Who needs adhesion?

Ultimate Freedom from Adhesion

It doesn't half look good!
At a cost...

A photograph of a high-speed train, likely a TGV, traveling on a concrete viaduct. The train is white with red and blue stripes. Below the viaduct is a paved road with a metal guardrail. The background shows green trees and a clear sky. The text 'Who needs adhesion?' is in the top right corner. The title 'Ultimate Freedom from Adhesion' is in large blue font. Below it, the text 'It doesn't half look good! At a cost...' is in black font.

Who needs adhesion?

Conclusions

- Adhesion operation is surprisingly capable;
- Atmospheric system was a failure;
- Cliff-lifts and funiculars know no limits;
- Rack railways are economical, to a point;
- Maglev is the ultimate solution;
- Acknowledgements:
 - Georges Trüb, Switzerland, for pictures;
 - Thomas Schmid, Switzerland, for pictures;
 - Roger Waller, Switzerland, for pictures;
 - Shaofeng Liu, for scanning books;
 - Various Contributors to Wiki Commons, for pictures.
- Phew!

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